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Neutron Physics Division

SDT3. NITROGEN BROOMSTICK EXPERIMENT

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Reference: E. A. Straker, "Experimental Evaluation of Minima in the Total Neutron Cross Sections of Several Shielding Materials," ORNL-TM-2242 (1968).

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Abstract

The experimental and calculational details for a CSEWG integral data testing shielding experiment are presented.

Description

This experiment was designed to test a given set of neutron total cross sections for nitrogen in the range 0.8-10 MeV. Figure 1 shows a schematic of the arrangement. The nitrogen sample was a cylinder approximately 4 in. in diameter and placed so that its axis coincided with the axis of the neutron beam. The sample was contained in a glass dewar. In order to reduce the effect of neutron inscattering in the sample, the distance from the neutron source (the Tower Shielding Reactor II) to the sample was 50 ft and the detector was 50 ft from the sample. The neutron beam was confined to a diameter of 3.5 in. by collimators placed between the reactor and sample near the sample position. To reduce air-scattering effects the reactor and detector were shielded with lead and water and the reactor beam and detector acceptance were tightly collimated.

The detector was a nominal 2 in. x 2 in. NE-213 scintillator. Separation of neutron- and gamma-induced pulses was made by a modified Forte circuit. Throughout this experiment, a 2-in.-thick sample of lead, not pictured in Fig. 1, was placed in the beam to reduce the gamma-ray intensity incident on the NE-213. The unfolding of the pulse-height distributions was accomplished using the FERDoR code.

Data

The uncollided transmitted spectra through 3 ft of nitrogen, the lead, and the dewar (density of nitrogen = 0.0347 atoms/barn·cm) as measured by the NE-213 spectrometer system is shown in Fig. 2. The error in the unfolding is such that the spectrum lies somewhere within the darkened area within 68% confidence limits. In addition, there is an estimated 5-10% error in the absolute measurements due to power calibration uncertainties.

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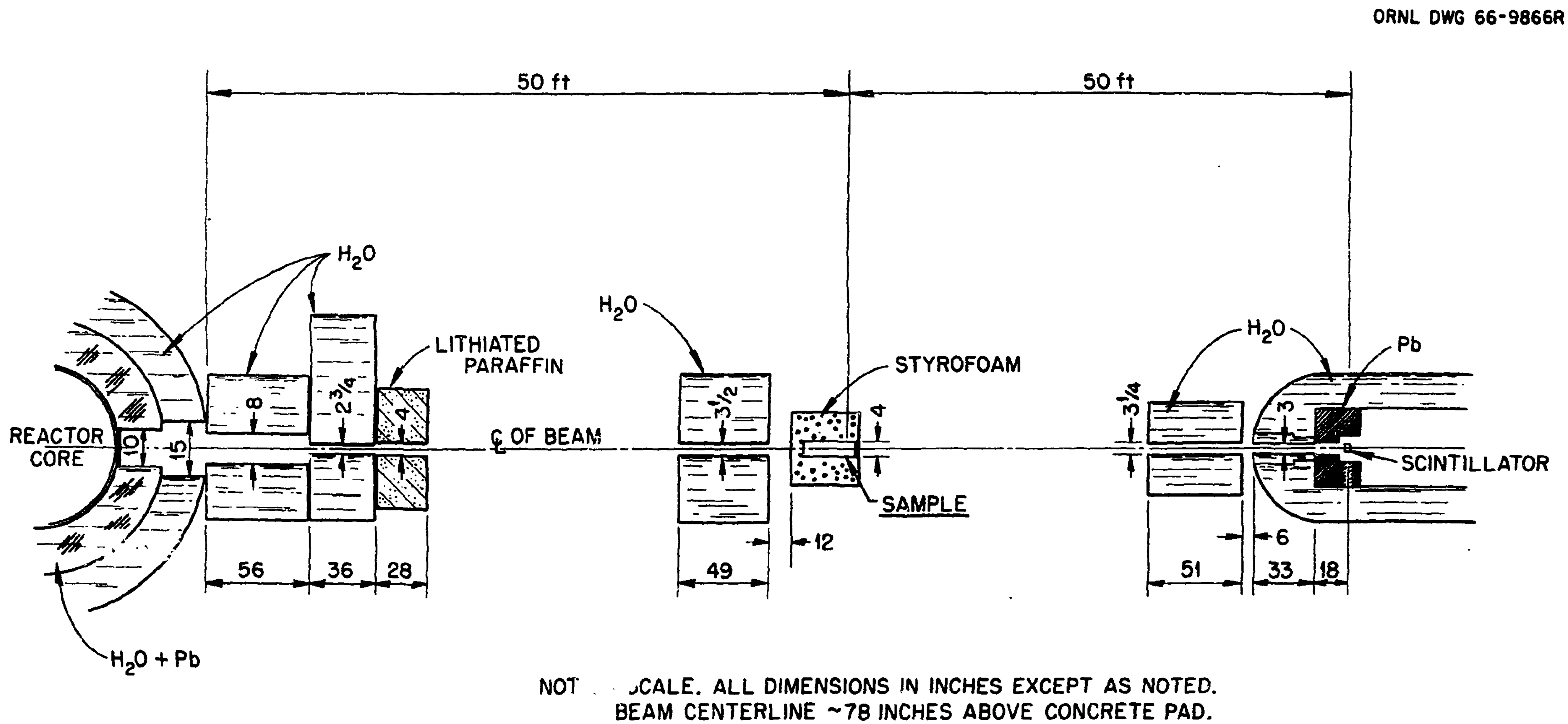

Fig. 1. Schematic of Experimental Arrangement.

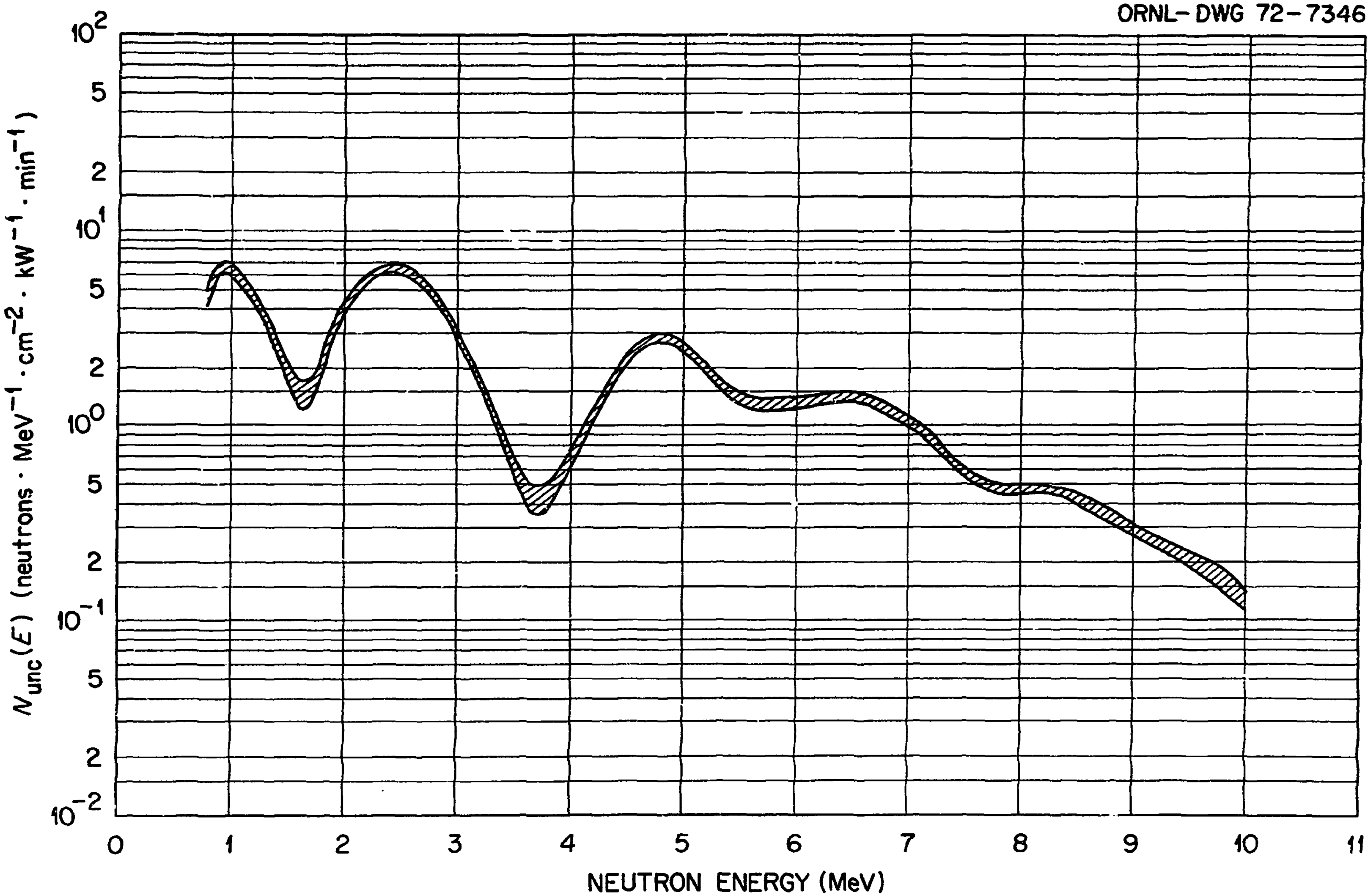

Fig. 2. Transmitted Spectrum Through Nitrogen.

The spectrum measured by the NE-213 at the same location when the nitrogen is removed from the beam, but with the empty dewar and lead still in place, is shown in Fig. 3 and tabulated in Table I. The resolution function of the NE-213 spectrometer system and unfolding procedure are shown in Table II, expressed as full width at half maximum (percent of peak energy).

Method of Calculation

The calculation consists first of determining a transmitted uncollided spectrum $N_{unc}(\Delta E')$.

$$N_{unc}(\Delta E') = \sum_{E_i \text{ in } \Delta E'} N_0(E_i) e^{-\Sigma_{tot}(E_i)t} \Delta E_i/\Delta E',$$

where $N_0(E_i)$ is taken or interpolated from Table I, t = 91.44 cm, and the energy intervals ΔE_i, which in general may be of variable width, are chosen sufficiently small that all of the structure in the vicinity of all of the minima in the total cross section is included. The total number of energy subintervals, ΔE_i, used in the region 0.5-12 MeV should follow as closely as possible the number suggested in the report sheet. The values of $N_{unc}(\Delta E')$ are to be binned into far fewer intervals, $(\Delta E')$, shown in the attached report sheet.

The second part of the calculation consists of folding the values of $N_{unc}(\Delta E')$ with the resolution function of the NE-213 spectrometer system:

$$N_{unc}(E) = \sum_{E'} N_{unc}(\Delta E') R(E' \rightarrow E) \Delta E'.$$

$R(E' \rightarrow E)$ is a gaussian centered at E', the midpoint of $\Delta E'$, and using the values appearing in Table II, becomes

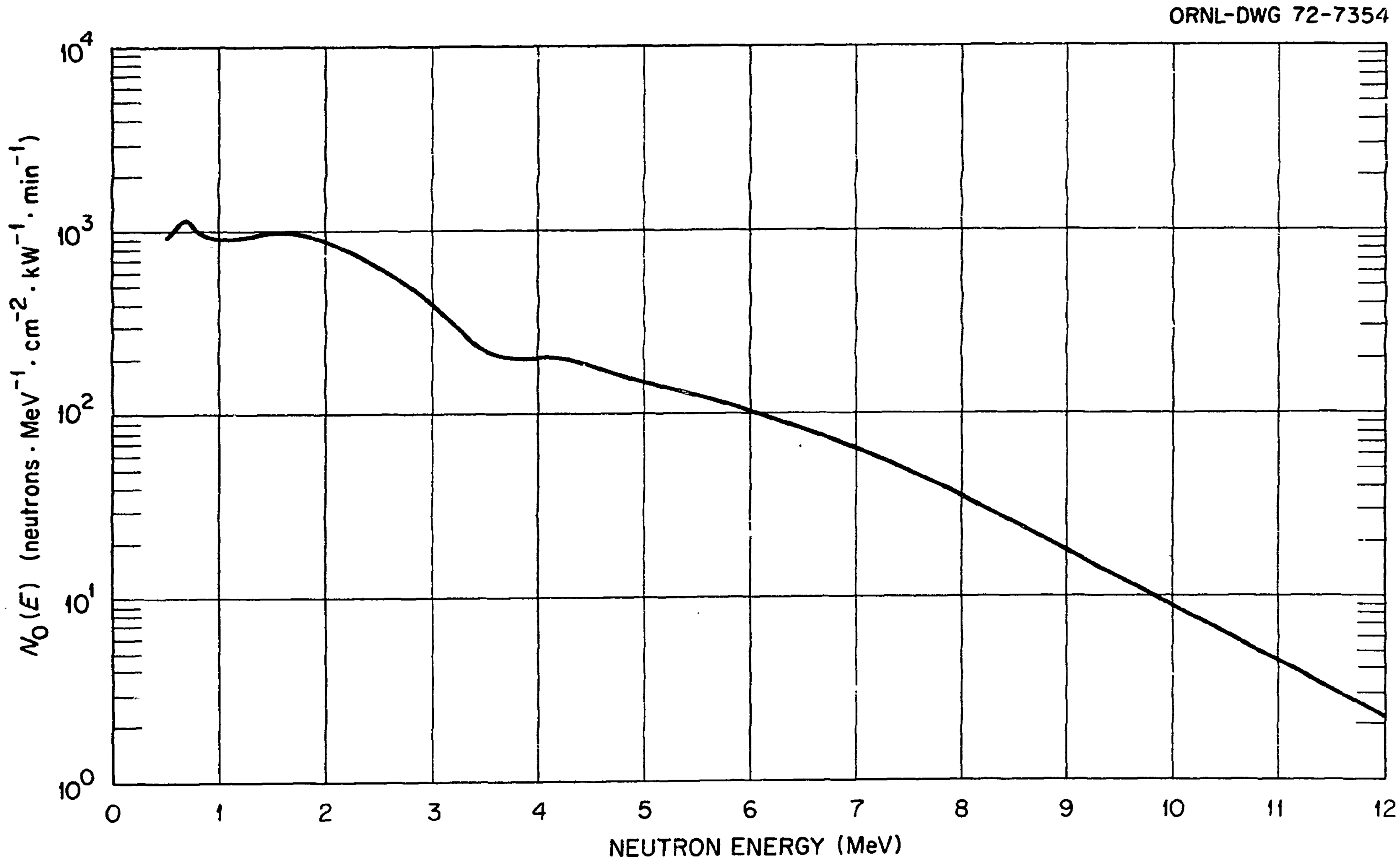

Fig. 3. Source Spectrum for Nitrogen.

Table I. Tabulated Source Spectrum (Spectrum Transmitted Through the Lead and Empty Dewar) in Units of Neutrons/MeV/cm^2/Kilowatt/Min as a Function of Energy in MeV*

E	$N_0(E)$	E	$N_0(E)$	E	$N_0(E)$	E	$N_0(E)$
0.5	940	2.2	795	4.4	190	8.2	29.8
0.55	975	2.3	740	4.5	182	8.4	26.1
0.6	1035	2.4	670	4.6	175	8.6	22.7
0.65	1125	2.5	625	4.7	169	8.8	19.9
0.7	1160	2.6	570	4.8	162	9.0	17.7
0.75	1100	2.7	520	4.9	158	9.2	15.1
0.8	975	2.8	475	5.0	151	9.4	13.2
0.85	955	2.9	435	5.2	137	9.6	11.5
0.9	930	3.0	395	5.4	125	9.8	10.1
0.95	920	3.1	350	5.6	114	10.0	8.9
1.0	910	3.2	305	5.8	105	10.2	7.6
1.1	920	3.3	270	6.0	100	10.4	6.7
1.2	930	3.4	245	6.2	94	10.6	5.9
1.3	940	3.5	227	6.4	87.4	10.8	5.0
1.4	965	3.6	213	6.6	80.6	11.0	4.4
1.5	970	3.7	203	6.8	73.8	11.2	3.8
1.6	965	3.8	195	7.0	67.0	11.4	3.4
1.7	955	3.9	193	7.2	59.0	11.6	3.0
1.8	920	4.0	199	7.4	51.1	11.8	2.6
1.9	910	4.1	200	7.6	44.8	12.0	2.2
2.0	885	4.2	199	7.8	39.2		
2.1	840	4.3	195	8.0	34.1		

*Interpolation in this table should follow the formula:

$$N_0(E) = \frac{E_2 - E}{E_2 - E_1} N_0(E_1) + \frac{E - E_1}{E_2 - E_1} N_0(E_2), \text{ where } E_1 \leq E \leq E_2.$$

Table II. Energy Resolution of the Spectrometer System*

E(MeV)	a FWHM/E(%)	E(MeV)	a FWHM/E(%)	E(MeV)	a FWHM/E(%)
0.5	47.5	3.3	18.8	6.2	13.5
0.6	44	3.4	18.5	6.4	13.2
0.7	41	3.5	18.2	6.6	13.0
0.8	38.5	3.6	18.0	6.8	12.8
0.9	36	3.7	17.7	7.0	12.6
1.0	33.5	3.8	17.4	7.2	12.4
1.1	32.5	3.9	17.1	7.4	12.2
1.2	31	4.0	16.9	7.6	12.1
1.3	30	4.1	16.7	7.8	11.9
1.4	29	4.2	16.5	8.0	11.8
1.5	27.5	4.3	16.3	8.2	11.6
1.6	26.5	4.4	16.1	8.4	11.5
1.7	26	4.5	15.9	8.6	11.4
1.8	25	4.6	15.7	8.8	11.3
1.9	24.5	4.7	15.5	9.0	11.2
2.0	24	4.8	15.3	9.2	11.1
2.1	23.5	4.9	15.2	9.4	10.9
2.2	23	5.0	15.1	9.6	10.8
2.3	22.5	5.1	14.9	9.8	10.7
2.4	22	5.2	14.7	10.0	10.5
2.5	21.5	5.3	14.5	10.2	10.3
2.6	21.2	5.4	14.4	10.4	10.2
2.7	20.8	5.5	14.3	10.6	10.1
2.8	20.4	5.6	14.2	10.8	10.0
2.9	20.1	5.7	14.1	11.0	9.8
3.0	19.7	5.8	13.9	11.4	9.7
3.1	19.4	5.9	13.8	11.8	9.6
3.2	19.1	6.0	13.7	12.2	9.6

*Interpolation in this table should follow the formula

$$a(E) = \frac{E_2 - E}{E_2 - E_1}\, a(E_1) + \frac{E - E_1}{E_2 - E_1}\, a(E_2)$$

where $E_1 \le E \le E_2$.

$$R(E' \to E) = \frac{93.944}{aE'} \exp - \left\{ \left[\frac{(E - E') \times 235.4820}{E'a} \right]^2 /2 \right\},$$

where a is the FWHM value at E' expressed in the units of Table II. The smeared calculated spectra, $N_{unc}(E)$ may then be compared directly with the reported experimental spectra.

Codes

A FORTRAN package is available to perform all the manipulation described in the preceding section. Subroutine XSECT and its subroutines access the total cross section from an ENDF/B tape and interpolate the cross section for any energy according to the interpolation scheme specified on the tape. It will only access pointwise data so that any evaluation at least partially described by resonance parameters above 500 keV cannot be accessed by this code. (See Table III.) It will be necessary to obtain a pointwise representation of the same tapes from Brookhaven in this instance. The main routine calculates the uncollided flux, smoothes the uncollided flux with the resolution function of the spectrometer system, and outputs the fluxes both before and after smoothing in the energy grid suggested in the report sheet.

The input data consist of the following cards:

Card A. T, ADEN (12F6.3). T, the thickness of the cylinder in centimeters, and ADEN the atomic density in atoms/barn·cm are shown in the following table (Table III).

Card B. ELEM(I),I=1,20(20A4). ELEM(I) is the element studied (see Table III).

Table III. Parameters Describing the Nitrogen Broomstick Experiment and the ENDF/B Evaluations Used to Compare With Experiment

ELEM(I)	T	ADEN	MATNØ	COMMENTS:
NITROGEN	91.44	0.0347	1133	No resonance parameters used. OK

Card C. MATNØ,MØDE, NDFB(12I6). MATNØ is the MAT number of the ENDF/B evaluation (see Table III), MØDE = 1 if binary, = 2 if BCD, and depends on the particular version of the tape an installation possesses, and NDFB is the logical tape number of the ENDF/B tape.

Cards D. ERG(I),I=1,86(12F6.3). The energy values in MeV at which the source is tabulated in Table I. ERG(1) = 0.50 and ERG(86) = 12.0.

Cards E. FZERØ(I),I=1,86(12F6.3). The source spectrum in units of neutrons/MeV/cm^2/kilowatt/min tabulated in Table I. FZERØ(1) = 940 and FZERØ(86) = 2.2.

Cards F. NINT(I),I=1,85(12I6). The number of subintervals ΔE_i within each $\Delta E'$ used in calculating the uncollided flux (see report sheet). Use the suggested values appearing in the report sheet. NINT(1) = 50 and NINT(85) = 20.

Cards G. ER(I),I=1,84(12F6.3). The energy value in MeV at which the resolution function of the spectrometer system is specified in Table II. ER(1) = 0.50 and ER(84) = 12.2.

Cards H. PCTWID(I),I=1,84(12F6.3). The values of a, the resolution of the spectrometer system, in units of percent of peak energy of the full width at half maximum, also tabulated in Table II. PCTWID(1) = 47.5 and PCTWID(84) = 9.6.

Cards I. ES(I),I=1,75(12F6.3). The energy values in MeV at which the smoothed uncollided spectrum is to be calculated (see the report sheet). ES(1) = 0.80 and ES(75) = 11.0.

The code requires a storage of approximately 92 K bytes (23 K words) on the IBM-360/75 or 360/91 computer with a running time of approximately 10 sec on the IBM-360/91.

Report sheet for the nitrogen "broomstick" experiment.

Calculated values of $N_{unc}(\Delta E')$ and approximate number of subintervals ΔE_i for each $\Delta E'$ used.

$\Delta E'$ (MeV)	$N_{unc}(\Delta E')$ (neut/cm^2/MeV/ kW/min)	Number of Subintervals $\Delta E'/\Delta E_i$	$\Delta E'$ (MeV)	$N_{unc}(\Delta E')$ (neut/cm^2/MeV/ kW/min)	Number of Subintervals $\Delta E'/\Delta E_i$
0.50-0.55	______	50	2.8-2.9	______	50
0.55-0.60	______	50	2.9-3.0	______	50
0.60-0.65	______	50	3.0-3.1	______	50
0.65-0.70	______	50	3.1-3.2	______	50
0.70-0.75	______	50	3.2-3.3	______	50
0.75-0.80	______	50	3.3-3.4	______	50
0.80-0.85	______	50	3.4-3.5	______	50
0.85-0.90	______	50	3.5-3.6	______	50
0.90-0.95	______	50	3.6-3.7	______	50
0.95-1.0	______	50	3.7-3.8	______	50
1.0-1.1	______	100	3.8-3.9	______	50
1.1-1.2	______	100	3.9-4.0	______	50
1.2-1.3	______	100	4.0-4.1	______	50
1.3-1.4	______	100	4.1-4.2	______	50
1.4-1.5	______	50	4.2-4.3	______	50
1.5-1.6	______	50	4.3-4.4	______	50
1.6-1.7	______	50	4.4-4.5	______	50
1.7-1.8	______	50	4.5-4.6	______	100
1.8-1.9	______	50	4.6-4.7	______	100
1.9-2.0	______	50	4.7-4.8	______	100
2.0-2.1	______	50	4.8-4.9	______	100
2.1-2.2	______	50	4.9-5.0	______	50
2.2-2.3	______	50	5.0-5.2	______	50
2.3-2.4	______	50	5.2-5.4	______	50
2.4-2.5	______	50	5.4-5.6	______	50
2.5-2.6	______	50	5.6-5.8	______	50
2.6-2.7	______	50	5.8-6.0	______	50
2.7-2.8	______	50	6.0-6.2	______	50

Report sheet for the nitrogen "broomstick" experiment (continued). Calculated values of $N_{unc}(\Delta E')$ and approximate number of subintervals ΔE_i for each $\Delta E'$ used.

$\Delta E'$ (MeV)	$N_{unc}(\Delta E')$ (neut/cm^2/MeV/ kW/min)	Number of Subintervals $\Delta E'/\Delta E_i$	$\Delta E'$ (MeV)	$N_{unc}(\Delta E')$ (neut/cm^2/MeV/ kW/min)	Number of Subintervals $\Delta E'/\Delta E_i$
6.2-6.4	______	50	9.2-9.4	______	50
6.4-6.6	______	50	9.4-9.6	______	20
6.6-6.8	______	50	9.6-9.8	______	20
6.8-7.0	______	50	9.8-10.0	______	20
7.0-7.2	______	50	10.0-10.2	______	20
7.2-7.4	______	50	10.2-10.4	______	20
7.4-7.6	______	50	10.4-10.6	______	20
7.6-7.8	______	50	10.6-10.8	______	20
7.8-8.0	______	50	10.8-11.0	______	20
8.0-8.2	______	50	11.0-11.2	______	20
8.2-8.4	______	50	11.2-11.4	______	20
8.4-8.6	______	50	11.4-11.6	______	20
8.6-8.8	______	50	11.6-11.8	______	20
8.8-9.0	______	50	11.8-12.0	______	20
9.0-9.2	______	50			

Report sheet for the nitrogen "broomstick" experiment (continued).

Calculated values of $N_{unc}(E)$, i.e., smoothed data to be compared with experiment.

E(MeV)	$N_{unc}(E)$ (neut/cm^2/MeV/kW/min)	E(MeV)	$N_{unc}(E)$ (neut/cm^2/MeV/kW/min)	E(MeV)	$N_{unc}(E)$ (neut/cm^2/MeV/kW/min)
0.8	______	3.1	______	6.2	______
0.85	______	3.2	______	6.4	______
0.9	______	3.3	______	6.6	______
0.95	______	3.4	______	6.8	______
1.0	______	3.5	______	7.0	______
1.1	______	3.6	______	7.2	______
1.2	______	3.7	______	7.4	______
1.3	______	3.8	______	7.6	______
1.4	______	3.9	______	7.8	______
1.5	______	4.0	______	8.0	______
1.6	______	4.1	______	8.2	______
1.7	______	4.2	______	8.4	______
1.8	______	4.3	______	8.6	______
1.9	______	4.4	______	8.8	______
2.0	______	4.5	______	9.0	______
2.1	______	4.6	______	9.2	______
2.2	______	4.7	______	9.4	______
2.3	______	4.8	______	9.6	______
2.4	______	4.9	______	9.8	______
2.5	______	5.0	______	10.0	______
2.6	______	5.2	______	10.2	______
2.7	______	5.4	______	10.4	______
2.8	______	5.6	______	10.6	______
2.9	______	5.8	______	10.8	______
3.0	______	6.0	______	11.0	______